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FPR-007
Issue No. 2
15 January 1963

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LONG-TIME INTERMITTENT CREEP

SECOND QUARTERLY PROGRESS REPORT

GENERAL DYNAMICS | FORT WORTH

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LONG-TIME INTERMITTENT CREEP

SECOND QUARTERLY PROGRESS REPORT

TO

APPLICATIONS LABORATORY

AERONAUTICAL SYSTEMS DIVISION

AIR FORCE SYSTEMS COMMAND

Contract AF33(657)-8907

Task No. 738103

by

O. N. Thompson
R. L. Jones

January 1963

FOREWORD

This is the second quarterly progress report to the Applications Laboratory, Aeronautical Systems Division, of the Air Force Systems Command, United States Air Force, on Long-Time Intermittent Creep. This research is being performed under Contract AF33(657)-8907, Task Number 738103.

The ASD Project Engineer for this task is Mr. Clayton L. Harmsworth (ASCREE-1) of the Applications Laboratory, Materials Central, Wright-Patterson Air Force Base.

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ABSTRACT

This program consists of measuring the effects of creep as well as the magnitude of creep resulting from steady and intermittent load application at 550°F and 650°F up to 30,000 hours. The materials under investigation are Ti8Al-1Mo-1V, Ti6AL-4V, AM350SCT, and PH15-7Mo stainless steels and Rene' 41 superalloy. This progress report describes the accomplishments to date in preparing for the test using multiple specimen testing on each creep machine.

1.0 INTRODUCTION

1.1 Reporting Period

This is the second quarterly progress report on "Long-Time Intermittent Creep" being performed at General Dynamics/Fort Worth, under Contract AF33(657)-8907, with the Aeronautical Systems Division of the United States Air Force. This contract was started on 1 July 1962 and will continue through 31 December 1963. This report covers only the work accomplished between 15 October 1962 and 15 January 1963.

1.2 Purpose of the Research

This research is essentially a testing program to determine design information on alloys exposed to stress and temperature for long periods of time. The alloys to be tested are those expected to find wide use in a supersonic transport. The temperature range and time span under load corresponds to the flight profile and desired life of a supersonic transport. The particular information to be obtained from this program is:

1. Creep strain versus time data for various stress levels
2. Influence of creep on the mechanical properties, metallographic characteristics, and the fracture toughness of the material.
3. Correlation between steady-state creep and intermittent creep effects.

1.3 <u>Materials</u>

The materials being evaluated are:

Titanium 8AL-1Mo-1V (duplex annealed)

Titanium 6AL-4V (mill annealed)

AM350SCT(825) stainless steel

PH15-7Mo (RH1100) stainless steel

Rene' 41 (20% cold worked + 16 hours at 1400°F) super alloy

1.4 <u>Test Conditions</u>

The program consists of four parts:

1. Evaluation of the materials prior to creep straining.
2. Evaluation of the materials after 1000, 5000, 10000, and 30000 hours of intermittent creep testing.
3. Evaluation of the materials after 30000 hours of steady creep.
4. Evaluation of the materials after 1000, 5000, 10000, and 30000 hours of heating without loading.

1.5 <u>Data to be Generated</u>

1.5.1 Creep strain measurements will be made to determine the creep strain with time for:

1. Steady creep for 30000 hours at 550°F.
2. Steady creep for 30000 hours at 650°F.
3. Intermittent creep for 1000 hours at 550°F.
4. Intermittent creep for 1000 hours at 650°F.
5. Intermittent creep for 5000 hours at 550°F.
6. Intermittent creep for 5000 hours at 650°F.

7. Intermittent creep for 10000 hours at 550°F.

8. Intermittent creep for 10000 hours at 650°F.

9. Intermittent creep for 30000 hours at 550°F.

10. Intermittent creep for 30000 hours at 650°F.

1.5.2 Specimens will be tested to determine F_{TU}, F_{TY}, % elongation, % reduction in area, fracture toughness (G_c and/or K_c), notched to unnotched strength ratio and metallographic changes due to creep.

1. Prior to exposure to creep, tested at room temperature
2. Prior to exposure to creep, tested at 550°F
3. Prior to exposure to creep, tested at 650°F
4. After intermittent creeping at 550°F, tested at room temperature
5. After intermittent creeping at 550°F, tested at 550°F
6. After intermittent creeping at 650°F, tested at room temperature
7. After intermittent creeping at 650°F, tested at 650°F
8. After steady creeping at 550°F, tested at room temperature
9. After steady creeping at 550°F, tested at 550°F
10. After steady creeping at 650°F, tested at room temperature
11. After steady creeping at 650°F, tested at 650°F
12. After heat soak only at 550°F, tested at room temperature

13. After heat soak only at 550°F, tested at 550°F

14. After heat soak only at 650°F, tested at room temperature

15. After heat soak only at 650°F, tested at 650°F

1.6 Creep test Stress Levels

The creep specimens will be loaded to give various creep strain rates. The stress levels of the 1000-hour creep exposure were aimed to fall in the region between 2/3 F_{TU} and yield stress at the creep temperature. This is as high as a material would be expected to sustain loads for any appreciable length of time. The AM350 stress level is below this target to provide a comparison between AM350 and PH15-7Mo stainless steel. Also, the Rene' 41 stress level falls slightly below 2/3 F_{TU}. The 30,000-hour creep stress levels were set by the ASD Project Engineer. The intermediate stress levels were set to divide the stress span between the 1000-hour creep stress level and the 30,000-hour creep stress level in approximately equal increments. These stress levels are shown in the table which follows. This table has been revised since the first quarterly progress report to more nearly agree with the static test results.

Material	Time Span (Hours)							
	1000		5000		10,000		30,000	
	550°F	650°F	550°F	650°F	550°F	650°F	550°F	650°F
Titanium 8Al-1Mo-1V	94,000	88,600	80,000	80,000	60,000	60,000	40,000	40,000
Titanium 6Al-4V	85,000		71,500		60,000		40,000	
AM350 SCT(825)	120,000	118,000	103,000	101,000	85,000	85,000	67,000	67,000
PH15-7Mo (RH1100)	120,000		103,000		85,000		67,000	
Rene' (20% Cold Worked +1400°F for 1600 Hours)	138,500	124,000	110,000	100,000	70,000	70,000	40,000	40,000

1.7 Test Set-Up

For a description of the test set-up, refer to the first quarterly progress report, Long-Time Intermittent Creep, Report No. -007, Issue I, dated 15 October 1962.

2.0 STATUS OF THE TASK

2.1 Oven Construction

During the time span of this report, all of the oven-blower-heater assemblies have been completed and insulated.

2.2 Power Supply

The additional wiring required to supply power to the heaters has been installed.

2.3 Controls

All of the electrical control panels, timers, switches etc., necessary for the automatic control of the intermittent heating-loading-unloading-cooling cycle have been installed. Check runs are now being made, using dummy specimens, to assure that each oven will perform as required.

2.4 Specimen Fabrication

All specimens have been machined and doublers have been spot welded to the ends as reinforcement around the loading holes.

2.5 Whiffle Trees

The whiffle trees for simultaneously loading the four specimen strips per creep machine have been completed and a load survey is underway to verify the load distribution.

2.6 Preliminary Testing

2.6.1 Static Tests

Static tests have been run to determine F_{TU}, F_{TY}, % elongation, and % reduction in area of the test materials prior to heat soaking or creep testing. This data will serve as a base line for determining any change in mechanical properties of the material when these same mechanical properties are measured after heat soaking alone or after creep testing. No fracture toughness measurements have been made to date.

2.6.2 Fatigue Tests

Fatigue tests have been run on the predrilled specimens for fracture toughness testing after intermittent creep loading. These tests indicate that the predrilled specimens may fail prematurely due to fatigue during the 1000-hour creep test. Therefore, the holes for starting the fatigue-cracked center notch will not be put into the fracture toughness specimens until after the creep exposure is completed.

3.0 DISCUSSION

3.1 Fatigue Tests

The specimens for determining G_c and K_c will be one inch wide by four inches long with a .375-inch fatigue cracked center notch. The plan is to creep test five specimens as a one-inch wide continous strip. After creep testing, the strip will be cut into the four-inch long specimens. It was also planned to have 3/16-inch diameter holes in the center of each specimen during the creep test. After creep testing the specimens were to be fatigue cracked. The 3/16-inch hole was to be notched by the "Elox" process, at its center line transverse to the specimen, and then subjected to cyclic loading to produce the 3/8-inch wide fatigue cracked notch.

However, due to the intermittent loading and unloading of the specimens during creep testing, the specimens might fail from fatigue. To determine if the strips with the center hole would survive the intermittent creep tests, fatigue tests were run at the stress levels for the 1000-hour creep test and, also, for the 30,000-hour creep tests. The loading cycle requires 2.5 hours at temperature for every three hours of testing. For 1,000 hours of testing, the number of cycles required are

$$\frac{1000}{3} = 333\text{-}1/3 \text{ or } 334 \text{ cycles.}$$

Likewise, for 30,000 hours of testing, 10,000 cycles will be required.

It was decided to run the tests at room temperature. To account for the variation in strength between room temperature and 550° or 650°F, the creep stress was multiplied by the ratio

$$\frac{\text{Room temperature ult. stress}}{\text{Elevated temperature, } 550^\circ \text{ or } 650^\circ\text{, ult. stress}}$$

to determine the maximum fatigue stress.

The Rene' 41 and the Ti8Al-1Mo-1V met the requirements for the 1,000-hour creep test. The AM350 and the Ti6Al-4V failed to reach the required number of cycles. The PH15-7Mo stainless steel was not tested. Following the fatigue testing simulating 1,000 hours of intermittent

creep, the tests simulating 30,000 hours of intermittent creep were run. All materials except the PH15-7Mo sustained the required cycles of loading.

On the basis of this testing, it was decided that predrilling the 3/16-inch holes would cause premature failure and, therefore, no holes would be drilled in the test specimen portion of the strips. Doublers were spot welded to both sides of the strips at the end loading holes for reinforcement.

A table of stress levels and cycles to failure for each specimen tested is shown on page.

3.2 Whiffle Tree Load Distribution

To accomplish this test with the available creep machines and the least elapsed time, the specimens were made in continuous strips of five specimens plus added material at each end for attaching the specimens to the creep machines. Four such strips will be loaded by each creep machine through a whiffle tree attached to the load beam. The whiffle trees were designed to distribute the dead weight from the load pan to each strip such that the stress at the test section agrees with the stresses shown on page.

The dimensions for the whiffle tree beams were calculated to the nearest .001 inch. The holes in the beams were drilled on the Fosdimatic tape-controlled

jig bore machine to $\pm$ .0005-inch tolerance. The pivots are coated with dry film lubricant to reduce friction.

To check the accuracy of the whiffle trees, the whiffle trees were loaded by dummy specimens in series with load cells. Dead weight was added to the creep machine load pan until the sum of the load cell readings equalled the desired applied load. This method of determining the dead weight balanced out the weight of the whiffle trees and specimens. With this technique the load cell readings agreed with the expected loads per specimen within 2.4 percent with 43 out of 56 load cells readings within less than one percent variation from the expected specimen load. A recheck was made of two whiffle trees having the highest variation and on the recheck the variation reversed sign indicating the accuracy of the whiffle trees is probably higher than the accuracy of the load cells.

3.3 Oven Temperature Distribution

Surveys of the temperature distribution in the creep ovens are being made. The aim is to maintain a uniform temperature distribution throughout the oven such that the maximum temperature difference of any specimens is $5^{o}F$ or less. To determine the temperature distribution, calibrated thermocouples were attached to dummy specimens at locations shown in the photograph on page 18.

Due to heat losses and a nonuniform air flow pattern within the oven, the temperature was found to vary as much as 20 degrees between the bottom center thermocouple (number 7) and the upper right hand thermocouple (number 8). This variation has been reduced to the required 5°F on the Number 1 oven. A deflector was added at the bottom of the oven to prevent direct impingement of the air blast on the lower portion of the specimens. Also, deflectors were added higher on the right-hand side directing the flow toward the cooler corner. A similar survey will be run on each oven prior to starting the creep test.

3.4 Oven Temperature Control

The oven temperature is controlled by a Brown "Electronik" recorder-controller equipped with anticipating proportioning controls. The sensor for the controller is a thermocouple mounted in contact with the specimens in the center of the oven. A recording of the temperature control that can be expected in the 550°F intermittent creep oven is shown on page 19. Some difficulty has been experienced in maintaining the control accuracy throughout a 24-hour time span. The regulators appear to be sensitive to line voltage variations and drift from time to time but the resulting temperature variation should be held to less than 10°F.

3.5 Schedule

The task is running behind the anticipated schedule. The schedule, as proposed, called for creep testing to start by 1 January. No ovens have been started to date. More time has been spent checking out temperature distributions, temperature control, whiffle tree load distributions and automatic control of the intermittent creep cycle than was anticipated. However, it is felt that the time spent to achieve accurate control and assure its continuance is well applied.

4.0 PLANS FOR THE NEXT QUARTER

As now planned, the first creep test will be started about 1 February. It is expected two ovens will be started per week until all 14 ovens are in operation.

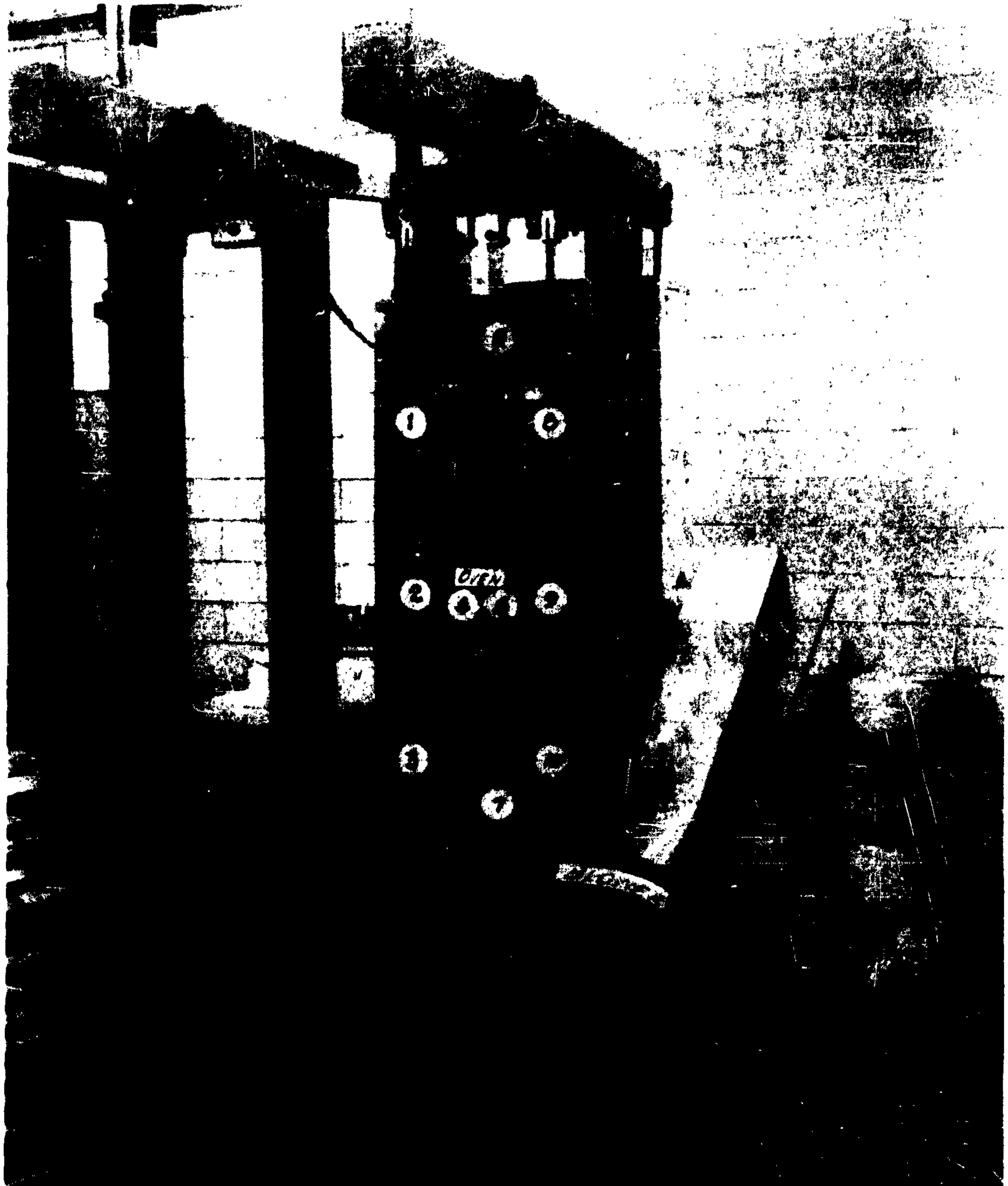
5.0 MATERIALS DATA

5.1 Fatigue Tests

The results of the preliminary fatigue tests are shown in Table I, page 20.

5.2 Static Tests

The static test results run on specimens prior to creep exposure are shown in Table II through Table VI, on pages 21 through 25.



THERMOCOUPLE LOCATIONS FOR OVEN TEMPERATURE SURVEY. OVEN IS CONTROLLED BY NO. 4. (OVEN SHOWN WITHOUT INSULATION FOR CLARITY)

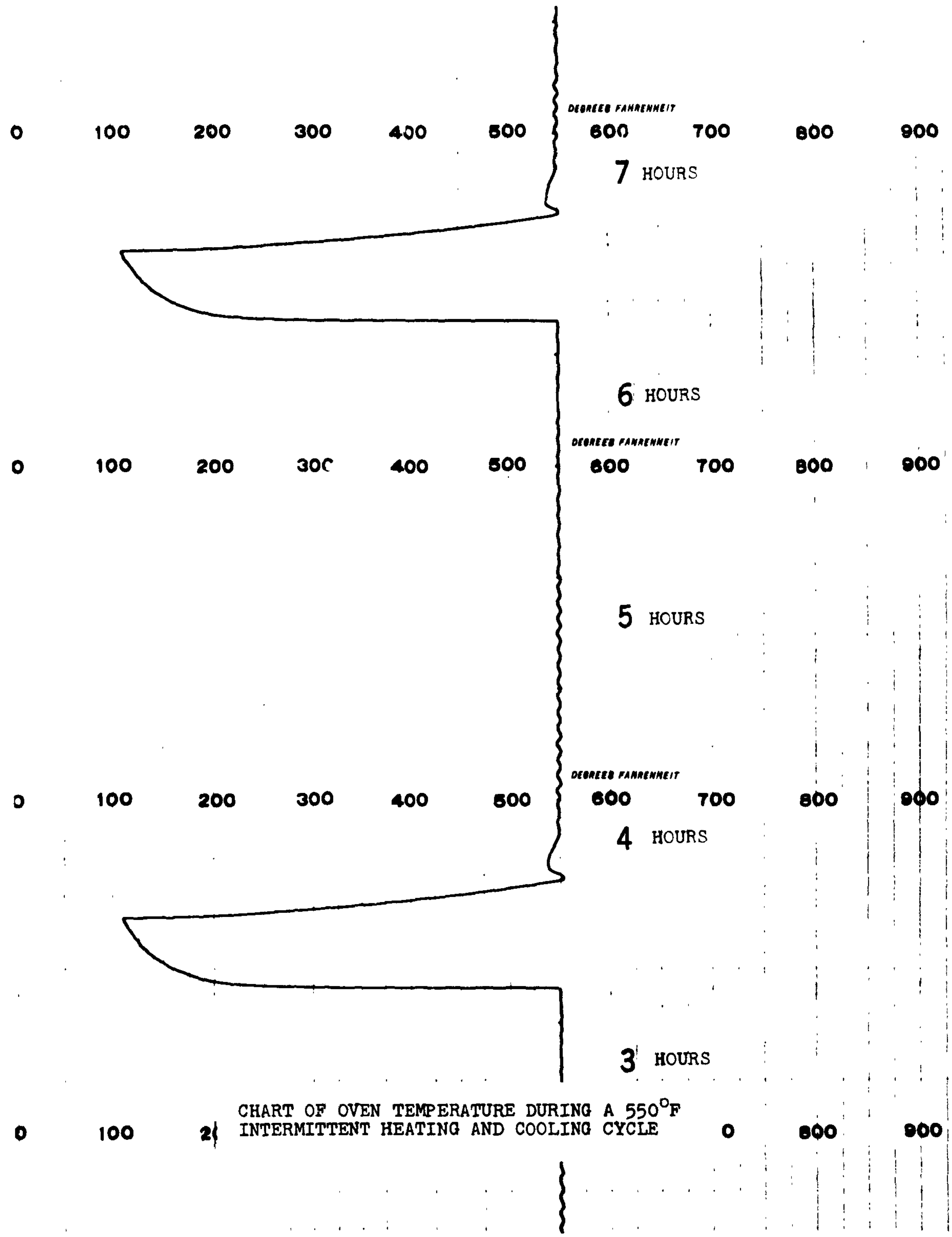


CHART OF OVEN TEMPERATURE DURING A 550°F INTERMITTENT HEATING AND COOLING CYCLE

TABLE I

FATIGUE TESTS OF SPECIMENS WITH 3/16-INCH CENTER HOLE

Test	Material	Stress Range	Cycles to Failure	Remarks
Simulated 1,000-Hour Intermittent Creep Test	Rene' 41	6500-131,000	400	Test stopped
		6500-131,000	400	Test stopped
		6500-131,000	400	Test stopped
	AM350	7500-150,000	272	Failed in upper grip at 131 cycles, in lower grip in 254 cycles and at center hole at 272 cycles
	Ti-8Al-1Mo-1V	6000-120,000	400	Test stopped
		6000-120,000	400	Test stopped
	Ti-6Al-4V	6000-120,000	13	
Simulated 30,000-Hour Intermittent Creep Test	Rene' 41	400- 40,000	24,000	Test stopped
		400- 40,000	20,000	Test stopped
			20,000	Test stopped
	AM 350	670- 67,000	12,000	Failed at lower grip
		670- 67,000	19,000	Failed at lower grip
			14,000	Failed at lower grip
			14,000	Failed at lower grip
	Ti-8Al-1Mo-1V	400- 40,000	42,000	Failed at lower grip
			38,000	Failed at lower grip
			20,000	Test stopped
	Ti-6Al-4V	400- 40,000	20,000	Test stopped
			20,000	Test stopped
	PH15-7Mo	670- 67,000	7	Failed at lower hole
		670- 67,000	7	Failed at lower hole
		670- 67,000	90	Failed at shoulder
		670- 67,000	81	Failed at shoulder
		670- 67,000	128	Failed at metal stamp

TABLE II

ROOM AND SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES OF Ti–6A–4U SHEET (MILL ANNEALED)

Test Temp. °F	Specimen No.	Thickness Inch	Yield Str. Ksi	Ult. Str. Ksi	Elong. % in 2"	R.A. %
RT	C1–1A	.0237	126.7	133.5	12.5	47.0
RT	C1–1B	.0242	131.5	139.4	12.5	45.5
RT	C1–1C	.0238	129.5	138.8	12.5	44.5
RT	C1–1D	.0235	125.9	134.9	10.5	44.4
RT	C1–1E	.0230	127.3	134.8	8.5*	44.1
RT	Avg.		128.2	136.3	12.0	45.1
550	C1–15A	.0224	89.9	105.3	9.5	37.3
550	C1–15C	.0244	88.8	105.3	11.5	40.3
550	C1–15D	.0233	89.4	105.7	10.0	39.8
550	C1–15E	.0223	89.2	105.1	8.0	40.5
550	C1–15F	.0253	87.9	104.5	11.0	41.4
550	Avg.		89.0	105.2	10.0	39.9
650	C1–16A	.0237	83.0	98.6	7.0	40.6
650	C1–16C	.0256	83.5	101.2	10.0	40.4
650	C1–16D	.0237	83.1	100.5	8.5	39.4
650	C1–16E	.0206	83.5	100.3	7.0	42.2
650	C1–16F	.0246	82.7	99.8	7.0	41.6
650	Avg.		83.2	100.1	7.9	40.8

*Broke outside gage mark – not included in average
1/2 hr. soak at temperature
Strain rate .005/in/in/min
TMCA Heat M 7858

TABLE III

ROOM AND SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES OF AM305 SHEET - CONDITION SCT (825°F)

Test Temp. °F	Specimen No.	Thickness Inch.	Yield Str. Ksi	Ult. Str. Ksi	Elong. % in 2"	R.A. %
RT	A1-1	.0247	178.5	209.6	9.5	51.3
RT	A1-2	.0247	181.8	210.3	10.0	50.3
RT	A1-3	.0249	178.7	208.1	9.0	52.4
RT	Avg.		179.7	209.3	9.5	51.3
550	A1-6	.0247	143.5	191.3	6.5	45.2
550	A1-7	.0248	146.0	189.0	6.5	44.8
550	A1-9	.0249	142.5	191.2	5.0	42.2
550	Avg.		144.0	190.5	6.0	44.1
650	A2-6	.0249	135.0	197.6	6.0	36.7
650	A3-6	.0251	139.3	196.7	7.0	38.0
650	A4-6	.0249	137.9	195.3	7.0	39.5
650	Avg.		137.4	196.5	6.7	38.1

1/2 hr. soak at temperature
Strain rate at temperature .005 in/in/min.
Allegheny Ludlum Heat 89324

TABLE IV

ROOM AND SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES OF PH15-7Mo SHEET (RH1100)

Test Temp. °F	Specimen No.	Thickness Inch.	Yield Str. Ksi	Ult. Str. Ksi	Elong. % in 2"	R.A. %
RT	B1-13F	.0237	143.6	170.0	11.5	52.2
RT	B1-13G	.0237	141.6	169.2	12.0	50.3
RT	B1-13H	.0237	143.1	169.3	12.0	50.4
RT	Avg.		142.8	169.5	11.8	51.0
550	B1-11A	.0234	135.2	147.4	6.0	48.5
550	B1-11B	.0236	134.4	147.6	6.0	46.2
550	B1-11C	.0235	133.8	146.6	6.0	50.0
550	Avg.		134.4	147.2	6.0	48.2

1/2 hr. soak at temperature
Strain rate at temperature .005 in/in/min.
Armco Heat 890610
Armco B-NAALB0106-130

TABLE V

ROOM AND SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES OF RENE' 41 SHEET (20% C.R. + 16 HRS. AT 1400°F)

Test Temp. °F	Specimen No.	Thickness Inch.	Yield Str. Ksi	Ult. Str. Ksi	Elong. % in 2"	R.A. %
RT	D3-15B	.0241	229.1	246.0	5.5	13.5
RT	D3-15C	.0239	230.5	246.2	5.5	15.1
RT	D3-15E	.0238	226.9	244.0	6.0	16.3
RT	D2-17E1	.0221	222.1	240.7	9.0	16.9
RT	D2-17E2	.0216	221.1	239.7	7.5	17.6
RT	Avg.		225.9	243.3	6.7	15.9
550	D3-3B	.0238	208.0	225.9	5.0*	—
550	D3-4B	.0241	206.6	227.0	6.5	44.4
550	D3-6B	.0249	203.9	220.3	3.5*	—
550	D3-15B	.0223	203.4	224.8	8.0	50.2
550	D2-13B	.0229	203.8	223.6	8.5	49.8
550	Avg.		205.1	224.3	7.7	48.1
650	D1-13B	.0228	211.0	229.0	7.0	45.6
650	D3-2B	.0225	205.4	223.4	6.0	51.6
650	D3-7B	.0250	206.0	210.8	2.5*	—
650	D3-9B	.0245	204.4	217.5	3.0*	—
650	D3-10B	.0241	204.5	222.7	5.0	44.8
650	Avg.		206.3	220.7		47.3

1/2 hr. soak at temperature
Strain rate at temperature .005/in/in/min.
Cannon Muskegon Heat V-2146

*Failed at extensometer grip - Value not included in average.

TABLE VI

ROOM AND SHORT TIME ELEVATED TEMPERATURE TENSILE PROPERTIES OF Ti-8Al-1Mo-1V SHEET (DUPLEX ANNEAL)

Test Temp. °F	Specimen No.	Thickness Inch.	Yield Str. Ksi	Ult. Str. Ksi	Elong. % in 2"	R.A. %
RT	E3-7B	.0264	146.7	154.3	20.0	35.0
RT	E3-8B	.0268	145.3	156.1	17.0	35.7
RT	E3-10B	.0267	146.7	157.2	15.0	38.3
RT	Avg.		146.2	155.9	17.3	36.3
550	E2-5A	.0265	100.7	126.1	12.5	38.1
550	E2-5C	.0272	98.6	121.6	13.5	36.4
550	E2-6A	.0272	99.1	124.1	13.5	37.3
550	E2-6B	.0275	99.1	124.1	13.0	36.5
550	Avg.		99.4	124.0	13.1	37.1
650	E2-4A	.0255	96.2	121.9	9.0	
650	E2-4B	.0271	96.5	120.9	9.0	
650	E2-4C	.0268	95.0	119.2	10.5	
650	E2-5B	.0272	——*	118.2	9.0	
650	E2-6C	.0270	94.1	118.8	10.5	
650	Avg.		95.5	119.8	9.6	

1/2 hr. soak at temperature
Strain rate .005 in/in/min.
TMCA Heat D-1237

*Extensometer slipped

6.0 DRAWINGS, DIAGRAMS, AND PHOTOGRAPHS

6.1 Individual Specimen Configuration

A drawing of the specimens prepared for testing after creep exposure or exposure to heat alone is shown on page 27.

6.2 Tandem Specimen Configuration

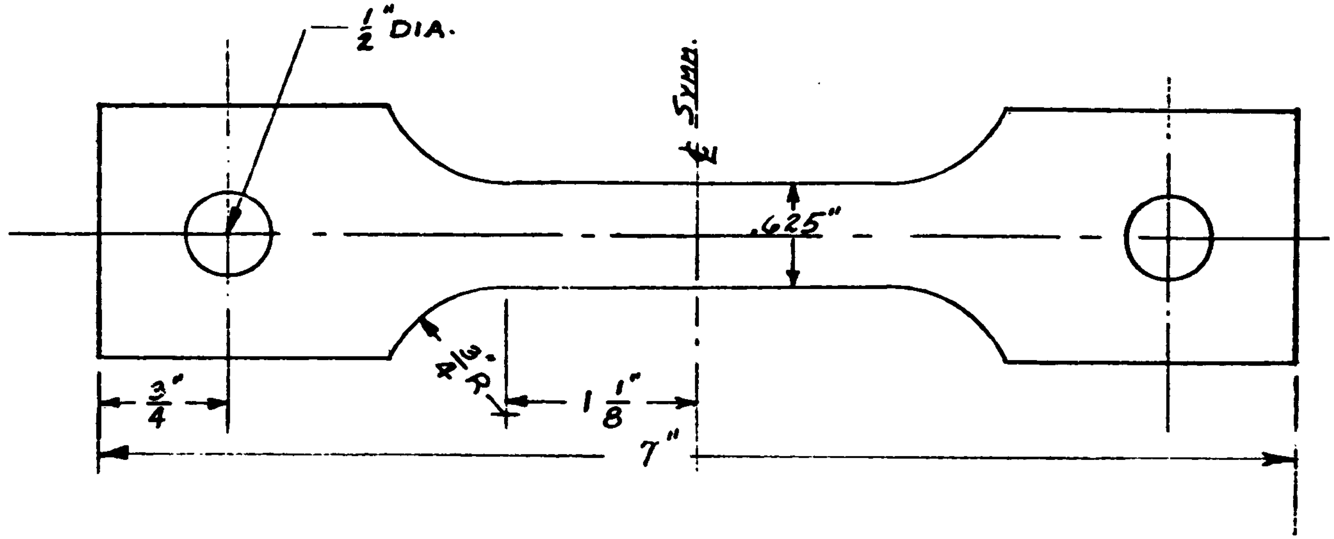
A drawing of the five specimens in tandem, as they will be exposed to creep or heat alone, is shown on page 28.

6.3 Intermittent Oven Control Record

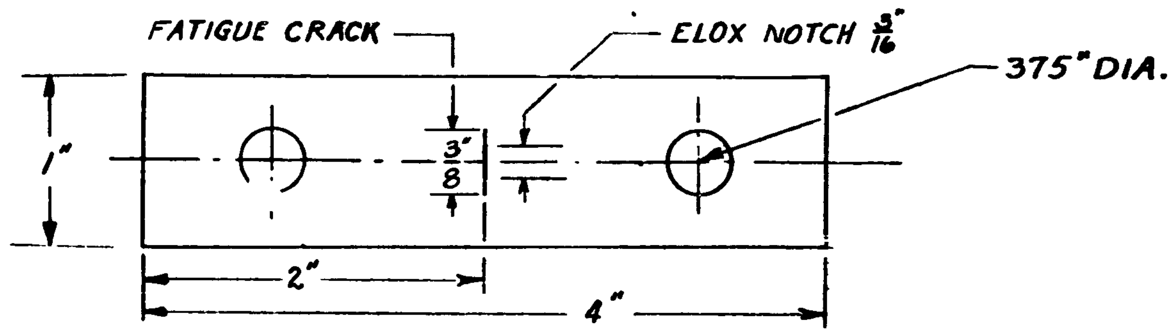
A recording of the temperature in a 550°F oven during a complete cycle of heat up to temperature, hold for 2.5 hours at temperature, cool-down and hold for 20 minutes is shown on page 19.

6.4 Thermocouple Locations in an Oven for Temperature Survey

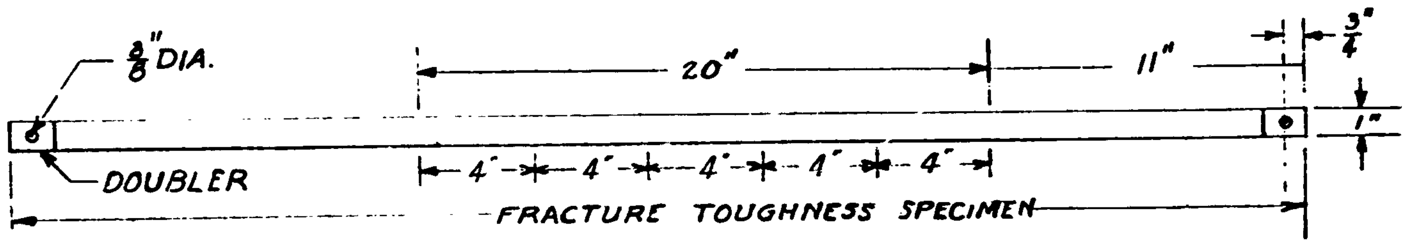
The thermocouples used during the temperature survey are located on the specimens as shown in the photograph on page . The Number 4 thermocouple served as the sensor for the temperature controller.



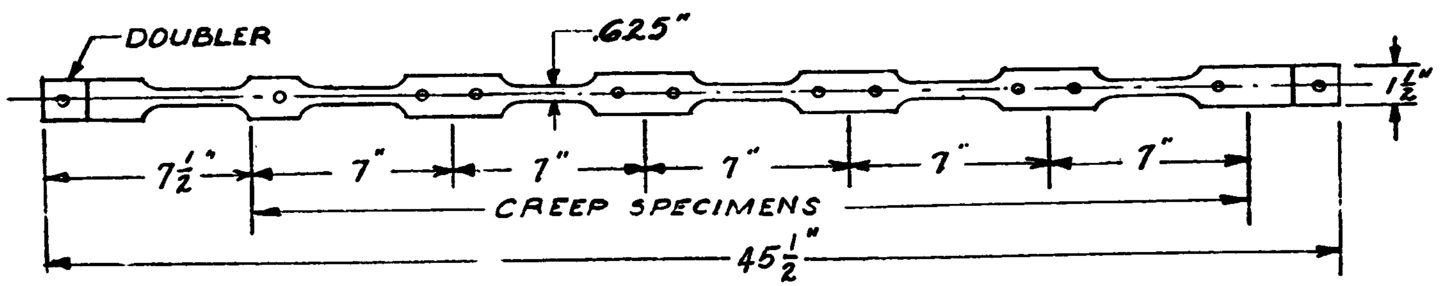
CREEP SPECIMEN FOR MECHANICAL PROPERTIES TEST
AFTER CREEP LOADING



CREEP SPECIMEN FOR FRACTURE TOUGHNESS TESTING
AFTER CREEP LOADING
(SPECIMEN NOTCHED AFTER CREEPING)



TANDEM CREEP SPECIMENS FOR MEASURING FRACTURE TOUGHNESS AFTER CREEP EXPOSURE



TANDEM CREEP SPECIMENS FOR MEASURING CREEP STRAIN DURING AND MECHANICAL PROPERTIES AFTER CREEP EXPOSURE

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